Chapter 6 Predictive Maintenance Technologies

6.1 Introduction

Predictive maintenance attempts to detect the onset of a degradation mechanism with the goal of correcting that degradation prior to significant deterioration in the component or equipment.

The diagnostic capabilities of predictive maintenance technologies have increased in recent years with advances made in sensor technologies. These advances, breakthroughs in component sensitivities, size reductions, and most importantly, cost have opened up an entirely new area of diagnostics to the O&M practitioner.

As with the introduction of any new technology, proper application and ***TRAINING*** is of critical importance. This need is particularly true in the field of predictive maintenance technology that has become increasing sophisticated and technology driven. Most industry experts would agree (as well as most reputable equipment vendors) that this equipment should not be purchased for in-house use if there is not a serious commitment to proper implementation, operator training, and equipment upkeep. If such a commitment cannot be made, a site is well advised to seek other methods of program implementation—a preferable option may be to contract for these services with an outside vendor and rely on their equipment and expertise.

6.2 Thermography

6.2.1 Introduction

Infrared (IR) thermography can be defined as the process of generating visual images that represent variations in IR radiance of surfaces of objects. Similar to the way objects of different materials and colors absorb and reflect electromagnetic radiation in the visible light spectrum (0.4 to 0.7 microns), any object at temperatures greater than absolute zero emits IR energy (radiation) proportional to its existing temperature. The IR radiation spectrum is generally agreed to exist between 2.0 and 15 microns. By using an instrument that contains detectors sensitive to IR electromagnetic radiation, a two-dimensional visual image reflective of the IR radiance from the surface of an object can be generated. Even though the detectors and electronics are different, the process itself is similar to that a video camera uses to detect a scene reflecting electromagnetic energy in the visible light spectrum, interpreting that information, and displaying what it detects on a liquid crystal display (LCD) screen that can then be viewed by the device operator.

Because IR radiation falls outside that of visible light (the radiation spectrum to which our eyes are sensitive), it is invisible to the naked eye. An IR camera or similar device allows us to escape the visible light spectrum and view an object based on its temperature and its proportional emittance of IR radiation. How and why is this ability to detect and visualize an object's temperature profile important in maintaining systems or components? Like all predictive maintenance technologies, IR tries to detect the presence of conditions or stressors that act to decrease a component's useful or design life. Many of these conditions result in changes to a component's temperature. For example, a loose or corroded electrical connection results in abnormally elevated connection temperatures due to increased electrical resistance. Before the connection is hot enough to result in equipment failure or possible fire, the patterns are easily seen through an IR imaging camera, the condition identified and corrected. Rotating equipment problems will normally result in some form of frictional change that will be seen as an increase in the component's temperature. Faulty or complete loss of refractory material will be readily seen as a change in the components thermal profile. Loss of a roof's membrane integrity will result in moisture that can be readily detected as differences in the roof thermal profile. These are just a few general examples of the hundreds of possible applications of this technology and how it might be used to detect problems that would otherwise go unnoticed until a component failed and resulted in excessive repair or downtime cost.

6.2.2 Types of Equipment

Many types of IR detection devices exist, varying in capability, design, and cost. In addition, simple temperature measurement devices that detect IR emissions but do not produce a visual image or IR profile are also manufactured. The following text and pictures provide an overview of each general instrument type.

Spot Radiometer (Infrared Thermometer) – Although not generally thought of in the world of thermography, IR thermometers use the same basic principles as higher end equipment to define an object's temperature based on IR emissions. These devices do not provide any image representative of an object's thermal profile, but rather a value representative of the temperature of the object or area of interest.

Figure 6.2.1. Typical IR spot thermometer.

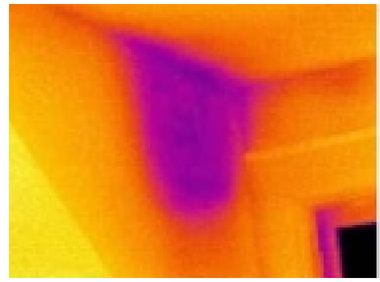


Figure 6.2.2. Internal house wall. Note dark area indicating cooler temperatures because of heat loss.

Infrared Imager - As indicated earlier, equipment capabilities, design, cost, and functionality vary greatly. Differences exist in IR detector material, operation, and design. At the fundamental level, IR detection devices can be broken down into two main groups- imagers and cameras with radiometric capability. A simple IR imager has the ability to detect an object's IR emissions and translate this information into a visual image. It does not have the capability to analyze and quantify specific temperature values. This type of IR detection device can be of use when temperature values are unimportant and the object's temperature profile (represented by the image) is all that is needed to define a problem. An example of such an application would be in detecting missing or inadequate insulation in a structure's envelope. Such an application merely requires an image representative of the differences in the thermal profile due to absence of adequate insulation. Exact temperature values are unimportant.

IR cameras with full radiometric capability detect the IR emissions from an object or camera field-of-view and translate this information into a visible format as in the case of an imager. In addition, these devices have the capability to analyze the image and provide temperature value for the area of interest. This capability is useful in applications where a temperature value is important in defining a problem or condition. For example, if an image indicated a difference between bearing housing temperature and the motor housing, it would be important in defining the problem to know the approximate temperature difference. This equipment and the supporting software can quantify temperatures anyplace within the IR image.

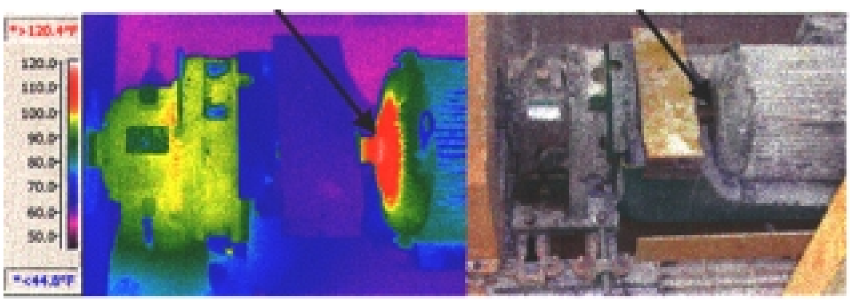


Figure 6.2.3. Hot motor bearing easily seen in IR image. Note the light area indicating a hot bearing.

6.2.3 System Applications

6.2.3.1 Electrical System Applications

The primary value of thermographic inspections of electrical systems is locating problems so that they can be diagnosed and repaired. "How hot is it?" is usually of far less importance. Once the problem is located, thermography and other test methods, as well as experience and common sense, are used to diagnose the nature of the problem. The following list contains just a few of the possible electrical system-related survey applications:

- Transmission lines
  - Splices
  - Shoes/end bells
    - Inductive heating problems
  - Insulators
    - Cracked or damaged/tracking
- Distribution lines/systems
  - Splices
  - Line clamps
  - Disconnects
  - Oil switches/breakers
  - Capacitors

  - Pole-mounted transformers
  - Lightning arrestors
  - Imbalances
- Substations
  - Disconnects, cutouts, air switches
  - Oil-filled switches/breakers (external and internal faults)
  - Capacitors
  - Transformers
    - Internal problems
    - Bushings
    - Oil levels
    - Cooling tubes
    - Lightning arrestors
  - Bus connections
- Generator Facilities
  - Generator
    - Bearings
    - Brushes
    - Windings
    - Coolant/oil lines: blockage
  - Motors
    - Connections
    - Bearings
    - Winding/cooling patterns
    - Motor Control Center
    - Imbalances
- In-Plant Electrical Systems
  - Switchgear
  - Motor Control Center
  - Bus
  - Cable trays
  - Batteries and charging circuits
  - Power/Lighting distribution panels.

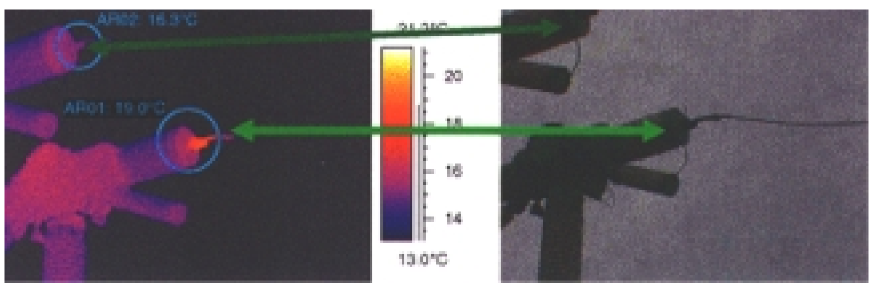


Figure 6.2.4. Air breaker problem. Note temperature difference between these air breaker contacts seen inside green circles.

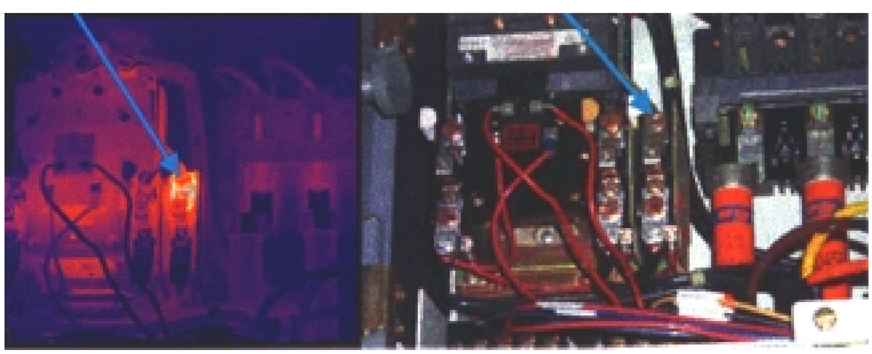


Figure 6.2.5. Overload connection problem. Note difference in IR image coloration between overload contacts.

6.2.3.2 Mechanical System Applications

Rotating equipment applications are only a small subset of the possible areas where thermography can be used in a mechanical predictive maintenance program. In addition to the ability to detect problems associated with bearing failure, alignment, balance, and looseness, thermography can be used to define many temperature profiles indicative of equipment operational faults or failure. The following list provides a few application examples and is not all inclusive:

- Steam Systems
  - Boilers
    - Refractory
    - Tubes
  - Traps
  - Valves
  - Lines
- Heaters and furnaces
  - Refractory inspections
  - Tube restrictions
- Fluids
  - Vessel levels
  - Pipeline blockages
- Environmental
  - Water discharge patterns
  - Air discharge patterns
- Motors and rotating equipment
  - Bearings
    - Mechanical failure
    - Improper lubrication
  - Coupling and alignment problems
  - Electrical connections on motors
  - Air cooling of motors.

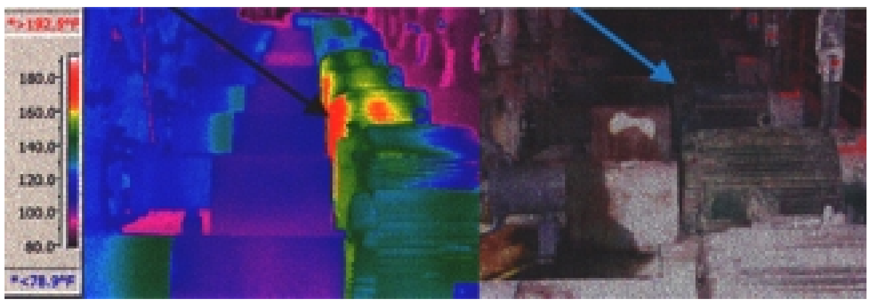


Figure 6.2.6. Warm inboard motor bearing. Image taken in a manner to readily compare IR images of several running motors.

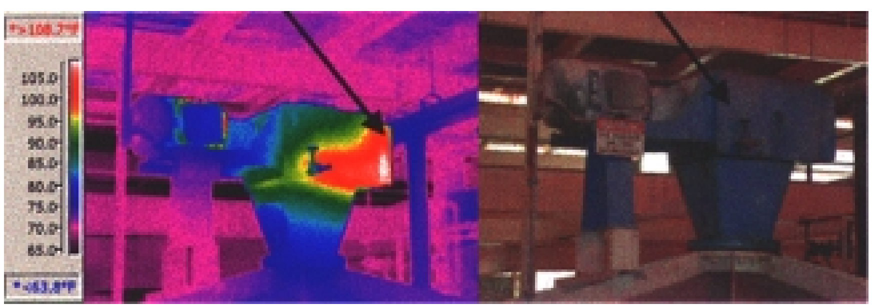


Figure 6.2.7. Possible gearbox problem indicated by white area defined by arrow. Design drawings of gearbox should be examined to define possible cause of elevated temperatures.

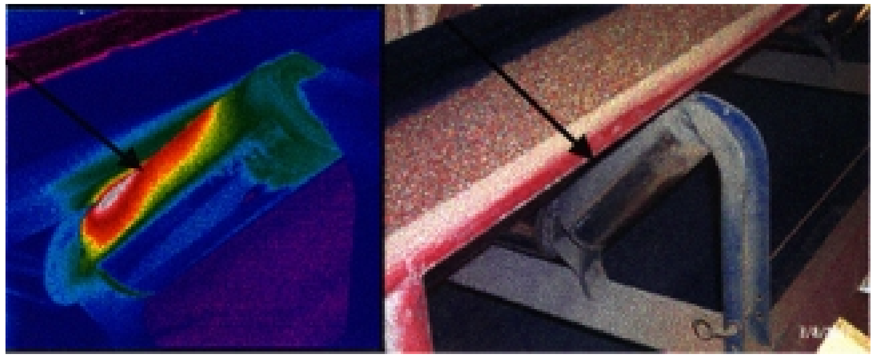


Figure 6.2.8. Seized conveyer belt roller as indicated by elevated temperatures in belt/roller contact area.

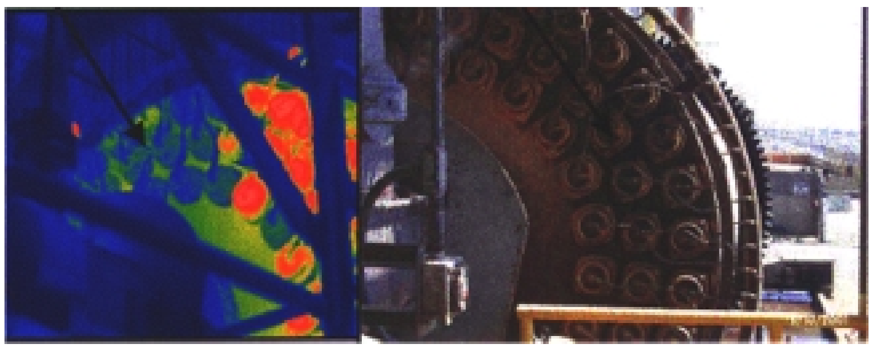


Figure 6.2.9. Inoperable steam heaters seen by cooler blue areas when compared to the operating heaters warmer red or orange colors.

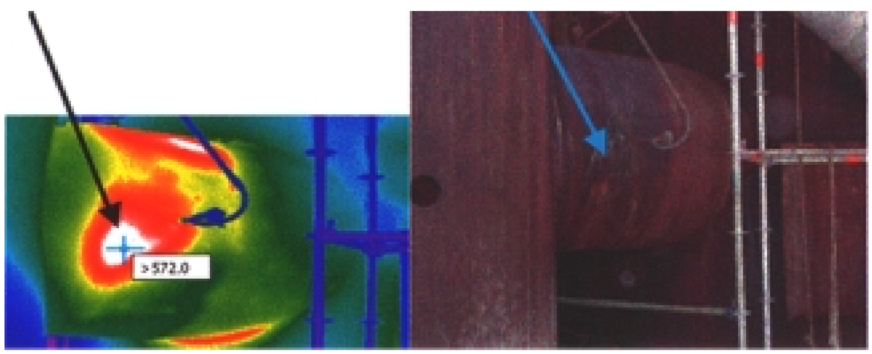
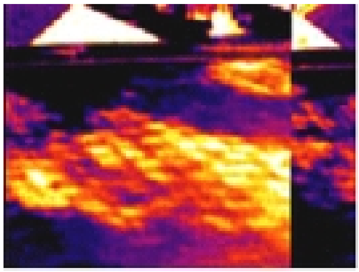
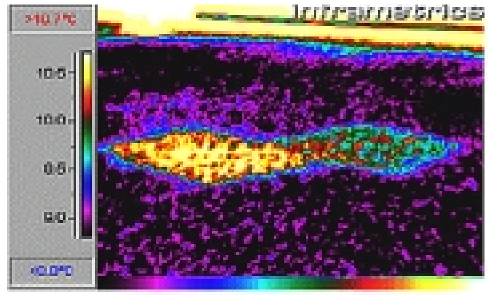


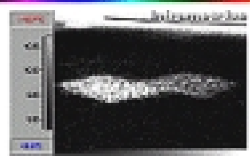
Figure 6.2.10. Refractory breakdown readily seen by white area in IR image.

6.2.3.3 Roof Thermography

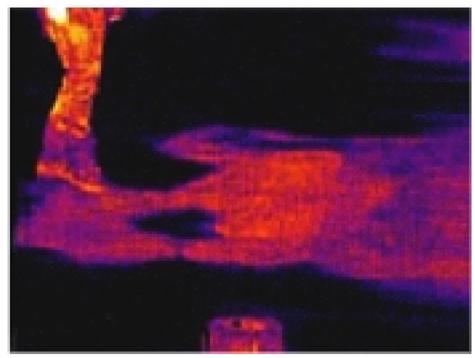
Out of sight, out of mind. This old adage is particularly true when it applies to flat roof maintenance. We generally forget about the roof until it leaks on our computers, switchgear, tables, etc. Roof replacement can be very expensive and at a standard industrial complex easily run into the hundreds of thousands of dollars. Depending on construction, length of time the roof has leaked, etc., actual building structural components can be damaged from inleakage and years of neglect that drive up repair cost further. Utilization of thermography to detect loss of a flat roof's membrane integrity is an application that can provide substantial return by minimizing area of repair/replacement. Roof reconditioning cost can be expected to run less than half of new roof cost per square foot. Add to this







These images show elevated temperatures of roof insulation due to difference in thermal capacitance of moisture-laden insulation.



the savings to be gained from reconditioning a small percentage of the total roof surface, instead of replacement of the total roof, and the savings can easily pay for roof surveys and occasional repair for the life of the building with change left over.

6.2.4 Equipment Cost/Payback

As indicated earlier, the cost of thermography equipment varies widely depending on the capabilities of the equipment. A simple spot radiometer can cost from $500 to $2500. An IR imager without radiometric capability can range from $12,000 to $20,000. A camera with full functionality can cost from $35,000 to $65,000. Besides the camera hardware, other program costs are involved. Computer hardware, personnel training, manpower, etc., needs to be accounted for in the budget. Below is a listing of equipment and program needs recommended by a company recognized as a leader in the world of IR program development:

- Level I thermographic training
- Level II thermographic training
- Ongoing professional development
- IR camera with wide-angle, normal, and telephoto lenses
- Report software
- Laptop computer
- Color printer

- Digital visual camera
- Personal Protective Equipment (PPE) for arc flash protection
- $80,000 IR camera and accessories
- $8,000 Level I and II training
- $45,000 - estimated annual loaded thermographer cost.

Payback can vary widely depending on the type of facility and use of the equipment. A production facility whose downtime equates to several thousands of dollars per hour can realize savings much faster than a small facility with minimal roof area, electrical distribution network, etc. On the average, a facility can expect a payback in 12 months or less. A small facility may consider using the services of an IR survey contractor. Such services are widely available and costs range from $600 to $1,200 per day. Contracted services are generally the most cost-effective approach for smaller, less maintenance-intensive facilities.

6.2.5 Case Studies

IR Diagnostics of Pump

A facility was having continual problems with some to its motor and pump combinations. Pump bearings repeatedly failed. An IR inspection confirmed that the lower thrust bearing was warmer than the other bearing in the pump. Further investigation revealed that the motor-pump combination was designed to operate in the horizontal position. In order to save floor space, the pump was mounted vertically below the motor. As a result, the lower thrust bearing was overloaded leading to premature failure. The failures resulted in a $15,000 repair cost, not including lost production time ($30,000 per minute production loss and in excess of $600 per minute labor).

IR Diagnostics of Steam Traps

Steam trap failure detection can be difficult by other forms of detection in many hard to reach and inconvenient places. Without a good trap maintenance program, it can be expected that 15% to 60% of a facility's traps will be failed open. At $3/1,000 lb (very conservative), a 1/4-in. orifice trap failed open will cost approximately $7,800 per year. If the system had 100 traps and 20% were failed, the loss would be in excess of $156,000. An oil refinery identified 14% of its traps were malfunctioning and realized a savings of $600,000 a year after repair.

IR Diagnostics of Roof

A state agency in the northeast operated a facility with a 360,000 square foot roof area. The roof was over 22 years old and experiencing several leaks. Cost estimates to replace the roof ranged between $2.5 and $3 million. An initial IR inspection identified 1,208 square feet of roof requiring replacement at a total cost of $20,705. The following year another IR inspection was performed that found 1,399 square feet of roof requiring replacement at a cost of $18,217. A roof IR inspection program was started and the roof surveyed each year. The survey resulted in less than 200 square feet of roof identified needing replacement in any one of the following 4 years (one year results were as low as 30 square feet). The total cost for roof repair and upkeep for the 6 years was less than $60,000. If the facility would have been privately owned, interest on the initial $3 million at 10% would have amounted to $300,000 for the first year alone. Discounting interest on $3 million over the 5-year period, simple savings resulting from survey and repair versus initial replacement cost ($3 million to

$60,000) amount to $2,940,000. This figure does not take into account interest on the $3 million, which would result in savings in excess of another $500,000 to $800,000, depending on loan interest paid.

6.2.6 References/Resources

The references and resources provided below are by no means all-inclusive. The listed organizations are not endorsed by the authors of this guide and are provided for your information only. To locate additional resources, the authors of this guide recommend contacting relevant trade groups, databases, and the world-wide web.

FLIR Systems, Boston
16 Esquire Road
North Billerica, MA 01862
Telephone: (978) 901-8000

Indigo Systems Corporation
5385 Hollister Avenue #103
Santa Barbara, CA 93111
Telephone: (805) 964-9797
Fax: (805) 964-7708

Mikron Instrument Company, Inc.
16 Thornton Road
Oakland, NJ 07436
Telephone: (805) 964-9797

Raytheon Infrared
Customer Service
Telephone: (800) 990-3275 (International)
Telephone: (972) 344-4000 (U.S. only)
Email: infrared@raytheon.com

Nikon, Inc.
1300 Walt Whitman Road
Melville, NY 11747-3064
Telephone: (631) 547-4200,
1-800-52-Nikon, or (516) 547-4355 (Electronic)

6.2.6.1 Infrared Service Companies

Cooper Electric
3883 Virginia Avenue
Cincinnati, OH 46227
Telephone: (613) 271-6000
Fax: (613) 627-3246

Fox Systems, Inc.
1771 US Hwy 41 SW
P.O. Box 1777
Calhoun, GA 30703

Hartford Steam Boiler
Engineering Services
Telephone: (800) 231-0907, ext. 1120
Email: Sandy_Sanor@hsb.com

Infrared Services, Inc.
P.O. Box 701
Littleton, CO 80160-0701
Voice: (303) 734-1746
Fax: (303) 734-1201

Thermal Vision
14 Grissom Place
Pueblo, CO 81001
Telephone: (719) 646-4073
Email: fps@rmi.net

6.2.6.2 Infrared Internet Resource Sites

Academy of Infrared Thermography (www.infraredtraining.net)

- Level I, II, and III certification information and training schedule.
- Online store (books, software, videos).
- Online resources (links, image gallery, message board).
- Communication (classifieds, news, industry related information.
- Company profile and contact information.

Snell Infrared (Snellinfrared.com)

- Training and course information.
- Industry links.
- IR library.
- Newsletter.
- Classifieds.
- IR application information.

FLIR Systems (www.flir.com)

- Product information.
- Image gallery.
- Application overview with images.
- Used camera source.

6.3 Oil Analysis

6.3.1 Introduction

One of the oldest predictive maintenance technologies still in use today is that of oil analysis. Oil analysis is used to define three basic machine conditions related to the machine's lubrication or lubrication system. First is the condition of the oil, i.e., will its current condition lubricate per design? Testing is performed to determine lubricant viscosity, acidity, etc., as well as other chemical analysis to quantify the condition of oil additives like corrosion inhibitors. Second is the lubrication system condition, i.e., have any physical boundaries been violated causing lubricant contamination? By testing for water content, silicon, or other contaminants (depending on the system design), lubrication system integrity can be evaluated. Third is the machine condition itself. By analyzing wear particles existing in the lubricant, machine wear can be evaluated and quantified.

In addition to system degradation, oil analysis performed and trended over time can provide indication of improperly performed maintenance or operational practices. Introduction of contamination during lubricant change-out, improper system flush-out after repairs, addition of improper lubricant, and improper equipment operation are all conditions that have been found by the trending and evaluation of oil analysis data.

Several companies provide oil analysis services. These services are relatively inexpensive and some analysis laboratories can provide analysis results within 24 hours. Some services are currently using the Internet to provide quick and easy access to the analysis reports. Analysis equipment is also available should a facility wish to establish its own oil analysis laboratory. Regardless of whether the analysis is performed by an independent laboratory or by in-house forces, accurate results require proper sampling techniques. Samples should be taken from an active, low-pressure line, ahead of any filtration devices. For consistent results and accurate trending, samples should be taken from the same place in the system each time (using a permanently installed sample valve is highly recommended). Most independent laboratories supply sample containers, labels, and mailing cartons. If the oil analysis is to be done by a laboratory, all that is required is to take the sample, fill in information such as the machine number, machine type, and sample date, and send it to the laboratory. If the analysis is to be done on-site, analytical equipment must be purchased, installed, and standardized. Sample containers must be purchased, and a sample information form created and printed.

The most common oil analysis tests are used to determine the condition of the lubricant, excessive wearing of oil-wetted parts, and the presence of contamination. Oil condition is most easily determined by measuring viscosity, acid number, and base number. Additional tests can determine the presence and/or effectiveness of oil additives such as anti-wear additives, antioxidants, corrosion inhibitors, and anti-foam agents. Component wear can be determined by measuring the amount of wear metals such as iron, copper, chromium, aluminum, lead, tin, and nickel. Increases in specific wear metals can mean a particular part is wearing, or wear is taking place in a particular part of the machine. Contamination is determined by measuring water content, specific gravity, and the level of silicon. Often, changes in specific gravity mean that the fluid or lubricant has been contaminated with another type of oil or fuel. The presence of silicon (usually from sand) is an indication of contamination from dirt.

6.3.2 Test Types

- **Karl Fischer Water Test** – The Karl Fischer Test quantifies the amount of water in the lubricant.

  Significance: Water seriously damages the lubricating properties of oil and promotes component corrosion. Increased water concentrations indicate possible condensation, coolant leaks, or process leaks around the seals.

- **ICP Spectroscopy** – Measures the concentration of wear metals, contaminant metals, and additive metals in a lubricant.

  Significance: Measures and quantifies the elements associated with wear, contamination, and additives. This information assists decision makers in determining the oil and machine condition.

- **Particle Count** – Measures the size and quantity of particles in a lubricant.

  Significance: Oil cleanliness and performance.

- **Viscosity Test** – Measure of a lubricant's resistance to flow at a specific temperature.

  Significance: Viscosity is the most important physical property of oil. Viscosity determination provides a specific number to compare to the recommended oil in service. An abnormal viscosity (±15%) is usually indicative of a problem.

- **FT-IR Spectroscopy** – Measures the chemical composition of a lubricant.

  Significance: Molecular analysis of lubricants and hydraulic fluids by FT-IR spectroscopy produces direct information on molecular species of interest, including additives, fluid breakdown products, and external contamination.

- **Direct Read Ferrography** – Measures the relative amount of ferrous wear in a lubricant.

  Significance: The direct read gives a direct measure of the amount of ferrous wear metals of different size present in a sample. Trending of this information reveals changes in the wear mode of the system.

- **Analytical Ferrography** – Allows analyst to visually examine wear particles present in a sample.

  Significance: A trained analyst visually determines the type and severity of wear deposited onto the substrate by using a high magnification microscope. The particles are readily identified and classified according to size, shape, and metallurgy.

- **Total Acid Number** – Measures the acidity of a lubricant.

  Description: Organic acids, a by-product of oil oxidation, degrade oil properties and lead to corrosion of the internal components. High acid levels are typically caused by oil oxidation.

6.3.3 Types of Equipment

Although independent laboratories generally perform oil analysis, some vendors do provide analysis equipment that can be used on-site to characterize oil condition, wear particles, and contamination. These devices are generally composed of several different types of test equipment and standards including viscometers, spectrometers, oil analyzers, particle counters, and microscopes. On-site testing can provide quick verification of a suspected oil problem associated with critical components such as water contamination. It can also provide a means to quickly define lubricant condition to determine when to change the lubricant medium. For the most part, detailed analysis will still require the services of an independent laboratory.

Typical oil analysis equipment available from several different vendors.

6.3.4 System Applications

- Turbines
- Boiler feed pumps
- Electrohydraulic control (EHC) systems
- Hydraulics
- Servo valves
- Gearboxes
- Roller bearings
- Anti-friction bearings
- Any system where oil cleanliness is directly related to longer lubricant life, decreased equipment wear, or improved equipment performance.

6.3.5 Equipment Cost/Payback

For facilities utilizing a large number of rotating machines that employ circulating lubricant, or for facilities with high dollar equipment using circulating lubricant, few predictive maintenance technologies can offer the opportunity of such a high return for dollars spent. Analysis for a single sample can run from $6 to $60 depending on the level of analysis requested. Given the high equipment replacement cost, labor cost, and downtime cost involved with a bearing or gearbox failure, a single failure prevented by the performance of oil analysis can easily pay for a program for several years.

6.3.6 Case Studies

Reduced Gear Box Failure

Through oil analysis, a company determined that each time oil was added to a gear reducer, contamination levels increased and this was accompanied by an increase in bearing and gear failures. Further examination determined that removing the cover plate to add oil allowed contamination from the process to fall into the sump. Based on this, the system was redesigned to prevent the introduction of contamination during oil addition. The result was a reduction in bearing/gearbox failure rates.

Oil Changes When Needed

A major northeast manufacturer switched from a preventive maintenance approach of changing oil in 400 machines using a time-based methodology to a condition-based method using in-house oil analysis. The oil is now being changed based on its actual condition and has resulted in a savings in excess of $54,000 per year.

Oil Changes and Equipment Scheduling

A northeast industrial facility gained an average of 0.5 years between oil changes when it changed oil change requirements from a preventive maintenance time-based approach to changing oil based on actual conditions. This resulted in greater than a $20,000 consumable cost in less than 9 months.

A large chemical manufacturing firm saved more than $55,000 in maintenance and lost production cost avoidance by scheduling repair of a centrifugal compressor when oil analysis indicated water contamination and the presence of high ferrous and non-ferrous particle counts.

6.3.7 References/Resources

The references and resources provided below are by no means all-inclusive. The listed organizations are not endorsed by the authors of this guide and are provided for your information only. To locate additional resources, the authors of this guide recommend contacting relevant trade groups, databases, and the world-wide web.

6.3.7.1 Analysis Equipment Resources

Computational Systems, Inc.
835 Innovation Drive
Knoxville, TN 37932
Telephone: (865) 675-2110
Fax: (865) 218-1401

Reliability Direct, Inc.
2911 South Shore Boulevard, Suite 170
League City, TX 77573
Telephone: (281) 334-0766
Fax: (281) 334-4255

Predict/DLI
Atlanta, GA (770) 974-8440
Cleveland, OH (216) 642-3223
Houston, TX (713) 680-1555
Milwaukee, WI (262) 896-9764
Seattle, WA (206) 842-7656
Email: Predictdli.com

Spectro, Inc.
Industrial Tribology Systems
160 Ayer Road
Littleton, MA 01460-1103
Telephone: (978) 486-0123
Fax: (978) 486-0030
E-Mail: Info@SpectroInc.com

6.3.7.2 Oil Analysis Laboratories

Computational Systems, Inc.
835 Innovation Drive
Knoxville, TN 37932
Telephone: (865) 675-2110
Fax: (865) 218-1501

Analysts, Inc.
20505 Earl Street
Torrance, CA 90503
Telephone: (800) 336-3637
Fax: (310) 370-6637

LubeTrak
561 Keystone Avenue, Suite 103
Reno, NV 89503-5331
Telephone: 1-866-582-3872 (Toll Free)
Email: LubeTrak.com

PdMA Corporation
5909-C Hampton Oaks Parkway
Tampa, FL 33610
Telephone: (813) 621-6563
Fax: (813) 620-0206

6.3.7.3 Internet Resource Sites

www.testoil.com
- Sample report
- Free oil analysis
- Industry related articles
- Test overview
- Laboratory services
- Training services

www.compsys.com
- Laboratory service
- Technical articles
- Application papers
- Sample report
- Training services
- Technical notes

www.pdma.com
- Related articles
- Training material
- Analysis services
- Industry links

6.4 Ultrasonic Analysis

6.4.1 Introduction

Ultrasonic, or ultrasounds, are defined as sound waves that have a frequency level above 20 kHz. Sound waves in this frequency spectrum are higher than what can normally be heard by humans. Non-contact ultrasonic detectors used in predictive maintenance detect airborne ultrasound. The frequency spectrums of these ultrasounds fall within a range of 20 to 100 kHz. In contrast to IR emissions, ultrasounds travel a relatively short distance from their source. Like IR emissions, ultrasounds travel in a straight line and will not penetrate solid surfaces. Most rotating equipment and many fluid system conditions will emit sound patterns in the ultrasonic frequency spectrum. Changes in these ultrasonic wave emissions are reflective of equipment condition. Ultrasonic signature analysis can be used to identify problems related to component wear as well as fluid leaks, vacuum leaks, and steam trap failures. A compressed gas or fluid forced through a small opening creates turbulence with strong ultrasonic components on the downstream side of the opening. Even though such a leak may not be audible to the human ear, the ultrasound will still be detectable with a scanning ultrasound device.

Ultrasounds generated in vacuum systems are generated within the system. A small percentage of these ultrasonic waves escape from the vacuum leak and are detectable, provided the monitoring is performed close to the source or the detector gain is properly adjusted to increase detection performance. In addition to system vacuum or fluid leaks, ultrasonic wave detection is also useful in defining abnormal conditions generated within a system or component. Poorly seated valves (as in the case of a failed steam trap) emit ultrasounds within the system boundaries as the fluid leaks past the valve seat (similar to the sonic signature generated if the fluid was leaking through the pipe or fitting walls). These ultrasounds can be detected using a contact-type ultrasonic probe.

Ultrasonic detection devices can also be used for bearing condition monitoring. According to National Aeronautics and Space Administration (NASA) research, a 12-50x increase in the amplitude of a monitored ultrasonic frequency (28 to 32 kHz) can provide an early indication of bearing deterioration.

Ultrasonic detection devices are becoming more widely used in detection of certain electrical system anomalies. Arcing/tracking or corona all produce some form of ionization that disturbs the air molecules around the equipment being diagnosed and produces some level of ultrasonic signature. An ultrasonic device can detect the high-frequency noise produced by this effect and translate it, via heterodyning, down into the audible ranges. The specific sound quality of each type of emission is heard in headphones while the intensity of the signal can be observed on a meter to allow quantification of the signal.

6.4.2 Types of Equipment

Ultrasonic analysis is one of the less complex and less expensive predictive maintenance technologies. The equipment is relatively small, light, and easy to use. Measurement data is presented in a straightforward manner using meters or digital readouts. The cost of the equipment is moderate and the amount of training is minimal when compared to other predictive maintenance technologies. The picture to the right shows a typical ultrasonic detection device.

Typical handheld ultrasonic detector.

Since ultrasounds travel only a short distance, some scanning applications could present a safety hazard to the technician or the area of interest may not be easily accessible. In these applications, the scanning device is generally designed with a gain adjust to increase its sensitivity, thereby allowing scanning from a greater distance than normal. Some ultrasonic detectors are designed to allow connection of a special parabolic dish-type sensing device (shown at left) that greatly extends the normal scanning distance.

Parabolic dish used with ultrasonic detector greatly extends detection range abilities.

6.4.3 System Applications

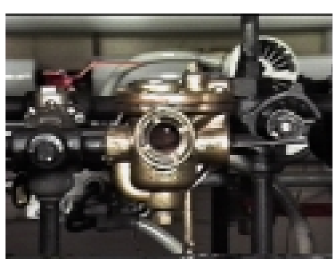
6.4.3.1 Pressure/Vacuum Leaks

- Compressed air
- Oxygen
- Hydrogen, etc.
- Heat exchangers
- Boilers
- Condensers
- Tanks
- Pipes
- Valves
- Steam traps.

Ultrasonic detection can be used to locate underground system leaks and detect heat exchanger tube leakage.

6.3.3.2 Mechanical Applications

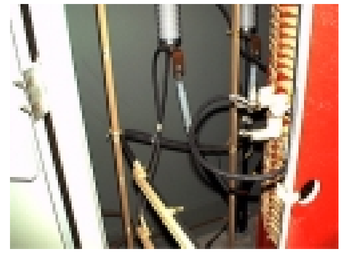
- Mechanical inspection
- Bearings
- Lack of lubrication
- Pumps
- Motors
- Gears/Gearboxes
- Fans
- Compressors
- Conveyers.



From steam trap faults and valve leakage to compressor problems, ultrasonic detection can be used to find a variety of problems that generate ultrasonic signatures.

6.4.3.3 Electrical Applications

- Arcing/tracking/corona
- Switchgear
- Transformers
- Insulators
- Potheads
- Junction boxes
- Circuit breakers.



Mechanical devices are not the only sources of ultrasonic emission. Electrical equipment will also generate ultrasonic waves if arcing/tracking or corona are present.

6.4.4 Equipment Cost/Payback

As indicated earlier, ultrasonic analysis equipment cost is minimal when compared to other predictive maintenance technologies. A hand-held scanner, including parabolic dish, software, probes, etc., will cost from $1,000 to $12,000. The minimal expense combined with the large savings opportunities will most often result in an equipment payback period of 6 months or less.

6.4.5 Case Studies

Ultrasound Detects Compressed Air Leaks

A northeast industrial plant was experiencing some air problems. The facility's two compressors were in the on mode for an inordinate amount of time, and plant management assumed a third compressor was needed, at a cost of $50,000. Instead, the foundry invested less than $1,000 in contracting an outside firm to perform an ultrasound inspection of its air system. In a single day, the ultrasound technician detected 64 air leaks accounting for an estimated total air loss of 295.8 cfm (26% of total system capacity). Considering it cost approximately $50,014 per year (calculated at $.04/kilowatt/hour) to operate the two air compressors, at a total of 1,120 cfm, correcting this air loss saved the plant $13,000 per year. In addition, the plant avoided having to spend another $50,000 on another air compressor, because after the leaks were found and repaired, the existing compressors were adequate to supply demand.

A Midwest manufacturer saved an estimated $75,900 in annual energy costs as a result of an ultrasound survey of its air system. A total of 107 air leaks were detected and tagged for repair. These leaks accounted for an air loss of 1,031 cfm, equal to 16% of the total 6,400 cfm produced by the air compressors that supply the facility.

6.4.6 References/Resources

The references and resources provided below are by no means all-inclusive. The listed organizations are not endorsed by the authors of this guide and are provided for your information only. To locate additional resources, the authors of this guide recommend contacting relevant trade groups, databases, and the world-wide web.

6.4.6.1 Equipment Resources

UE Systems
14 Hayes Street
Elmsford, NY 10523
Telephone: (914) 592-1220
Fax: (914) 347-2181

CTRL Systems, Inc.
1004 Littlestown Pike, Suite H
Westminster, MD 21157
Telephone: (877) 287-5797

Specialized Diagnostic Technologies, Inc.
8711A-50th Street, Suite 202
Edmonton, Alberta
T6B 1E7
Telephone: (780) 440-1362
Fax: (780) 440-0373
Email: sdtwest@sdt-canada.com

Superior Signal Company
P.O. Box 96
Spotswood, NJ 08884
Telephone: 1-800-945-TEST(8378) or
(732) 251-0800
Fax: (732) 251-9442

6.4.6.2 Service Companies

Plant Support and Evaluations, Inc.
2921 South 160th Street
New Berlin ,WI 53151
Telephone: 1-888-615-3559

PMCI
2500 Estes Avenue
Elk Grove Village, IL 60007
Telephone: 1-800-222-PMCI

Mid-Atlantic Infrared Services, Inc.
5309 Mohican Road
Bethesda, MD 21270
Telephone: (301) 320-2870

UE Systems, Inc.
Telephone: (914) 592-1220 or 1-800-223-1325
(Toll Free)
Fax: (914) 347-2181
Email: info@uesystems.com

6.4.6.3 Internet Resource Sites

www.uesystems.com
- Technology overview
- Training
- Links
- Sound demos.

www.superiorsignal.com
- Technology overview
- Ultrasonic sound bites (examples)
- Ultrasonic spectral graphs.

6.5 Vibration Analysis

6.5.1 Introduction

As all of us who ride or drive an automobile with some regularity know, certain mechanical faults or problems produce symptoms that can be detected by our sense of feel. Vibrations felt in the steering wheel can be an indicator of an out-of-balance wheel or looseness in the steering linkage. Transmission gear problems can be felt on the shift linkage. Looseness in exhaust system components can sometimes be felt as vibrations in the floorboard. The common thread with all these problems is that degeneration of some mechanical device beyond permissible operational design limitations has manifested itself by the generation of abnormal levels of vibration. What is vibration and what do we mean by levels of vibration? The dictionary defines vibration as "a periodic motion of the particles of an elastic body or medium in alternately opposite directions from the position of equilibrium when that equilibrium has been disturbed or the state of being vibrated or in vibratory motion as in (1) oscillation or (2) a quivering or trembling motion."

The key elements to take away from this definition are one: vibration is motion. Second, this motion is cyclic around a position of equilibrium. How many times have you touched a machine to see if it was running? You are able to tell by touch if the motor is running because of vibration generated by motion of rotational machine components and the transmittal of these forces to the machine housing. Many parts of the machine are rotating and each one of these parts is generating its own distinctive pattern and level of vibration. The level and frequency of these vibrations are different and the human touch is not sensitive enough to discern these differences. This is where vibration detection instrumentation and signature analysis software can provide us the necessary sensitivity. Sensors are used to quantify the magnitude of vibration or how rough or smooth the machine is running. This is expressed as vibration amplitude. This magnitude of vibration is expressed as:

- **Displacement** – The total distance traveled by the vibrating part from one extreme limit of travel to the other extreme limit of travel. This distance is also called the "peak-to-peak displacement."
- **Velocity** – A measurement of the speed at which a machine or machine component is moving as it undergoes oscillating motion.
- **Acceleration** – The rate of change of velocity. Recognizing that vibrational forces are cyclic, both the magnitude of displacement and velocity change from a neutral or minimum value to some maximum. Acceleration is a value representing the maximum rate that velocity (speed of the displacement) is increasing.

Various transducers are available that will sense and provide an electrical output reflective of the vibrational displacement, velocity, or acceleration. The specific unit of measure to best evaluate the machine condition will be dependent on the machine speed and design. Several guidelines have been published to provide assistance in determination of the relative running condition of a machine. An example is seen in Figure 6.5.1. It should be said that the values defined in this guideline, or similar guidelines, are not absolute vibration limits above which the machine will fail and below which the machine will run indefinitely. It is impossible to establish absolute vibration limits. However, in setting up a predictive maintenance program, it is necessary to establish some severity criteria or limits above which action will be taken. Such charts are not intended to be used for establishing vibration acceptance criteria for rebuilt or newly installed machines. They are to be used to evaluate the general or overall condition of machines that are already installed and operating in service. For those, setting up a predictive maintenance program, lacking experience or historical data, similar charts can serve as an excellent guide to get started.

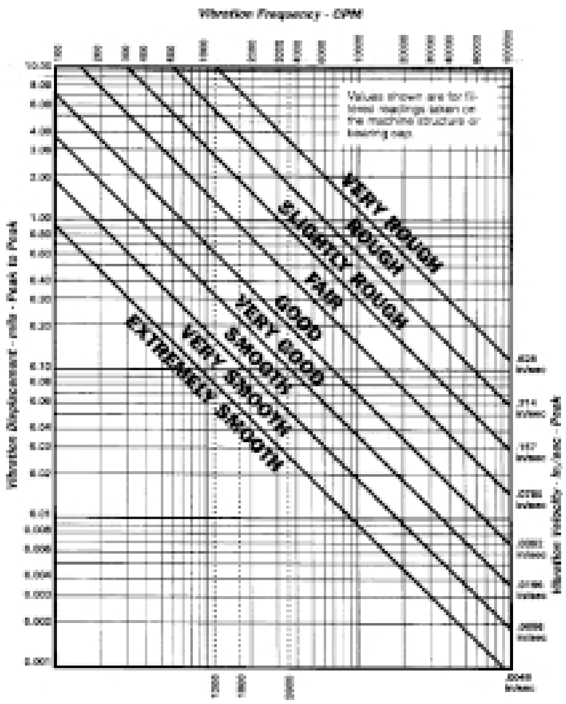


Figure 6.5.1. Vibration severity chart.

As indicated earlier, many vibration signals are generated at one time. Once a magnitude of vibration exceeds some predetermined value, vibration signature analysis can be used in defining the machine location that is the source of the vibration and in need of repair or replacement. By using analysis equipment and software, the individual vibration signals are separated out and displayed in a manner that defines the magnitude of vibration and frequency (Figure 6.5.2). With the understanding of machine design and operation, an individual schooled in vibration signature analysis can interpret this information to define the machine problem to a component level.

6.5.2 Types of Equipment

Depending on the application, a wide variety of hardware options exist in the world of vibration. Although not complicated, actual hardware requirements depend on several factors. The speed of the machine, on-line monitoring versus off-line data collection, analysis needs, signal output requirements, etc., will affect the type of equipment options available. Regardless of the approach, any vibration program will require a sensing device (transducer) to measure the existing vibration and translate this information into some electronic signal. Transducers are relatively small in size (see Figure 6.5.3) and can be permanently mounted or affixed to the monitoring location periodically during data collection.

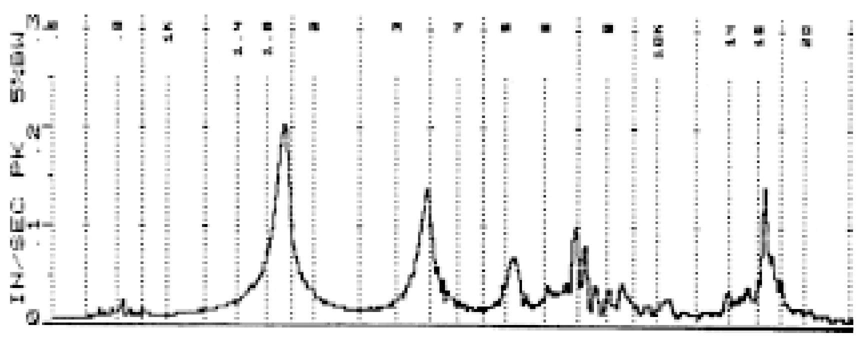


Figure 6.5.2. FFT - Example of graph breaking down vibration level at different frequencies

Figure 6.5.3. Typical vibration transducers.

In some cases, the actual translation of the vibration to an electrical signal occurs in a hand-held monitoring device. A metal probe attached to a hand-held instrument is held against a point of interest and the instrument translates the motions felt on the probe to some sort of electrical signal. Other portable devices utilize a transducer and hand-held data collection device. Both styles will provide some sort of display where the vibration magnitude is defined. Styles and equipment size vary greatly, but equipment is designed to be portable.

Examples of typical handheld vibration sensing meters. Note readout providing immediate level indication.

In addition to instruments designed to measure vibration magnitude, many manufacturers provide instrumentation that will perform signal analysis as well. Some equipment is designed to perform this analysis in the field while other equipment designs may require the use of an external PC.

Typical Vibration Analyzer – Note liquid crystal display providing actual vibration waveform information in addition to machine condition analytical capabilities.

6.5.3 System Applications

Vibration monitoring and analysis can be used to discover and diagnose a wide variety of problems related to rotating equipment. The following list provides some generally accepted abnormal equipment conditions/faults where this predictive maintenance technology can be of use in defining existing problems:

- Unbalance
- Eccentric rotors
- Misalignment
- Resonance problems
- Mechanical looseness/weakness
- Rotor rub
- Sleeve-bearing problems
- Rolling element bearing problems
- Flow-induced vibration problems
- Gear problems
- Electrical problems
- Belt drive problems.

Analyzing equipment to determine the presence of these problems is not a simple and easily performed procedure. Properly performed and evaluated vibration signature analysis requires highly trained and skilled individuals, knowledgeable in both the technology and the equipment being tested. Determination of some of the problems listed is less straightforward than other problems and may require many hours of experience by the technician to properly diagnosis the condition.

6.5.4 Equipment Cost/Payback

As indicated earlier, the styles, types, and capabilities of vibration monitoring equipment vary greatly. Naturally, equipment cost follows this variance. Transducers can cost under $100. The expected cost for vibration metering devices capable of defining magnitude with no analysis capability is approximately $1000. The cost goes up from there. A high-end vibration analyzer with software and all the accessories can exceed $50,000. A typical industrial site can expect to recover the cost of the high-end equipment investment within 2 years. Sites with a minimal number of rotating equipment, low-cost equipment installations, and/or no production related concerns may find it uneconomically advantageous to purchase a $50,000 vibration analysis system. These facilities may be wise to establish an internal program of vibration monitoring using a low-cost vibration-metering device and then employ the services of an outside contractor to conduct periodic surveys. These services generally range in cost from $600 to $1200 per day.

6.5.5 Case Studies

Vibration Analysis on Pump

Vibration analysis on a 200-hp motor/pump combination resulted in determination of improperly sized shaft bearings on both the pump end and the motor end. Repair costs were less than $2,700. Continued operation would have led to failure and a replacement cost exceeding $10,000.

6.5.6 References/Resources

The references and resources provided below are by no means all-inclusive. The listed organizations are not endorsed by the authors of this guide and are provided for your information only. To locate additional resources, the authors of this guide recommend contacting relevant trade groups, databases, and the world-wide web.

6.5.6.1 Equipment Resources

Wilcoxon Research, Inc.
21 Firstfield Road
Gaithersburg, MD 20878
Telephone: (301) 330-8811 or
1-800-WILCOXON
Email: sensors@wilcoxon.com
Web site: www.wilcoxon.com

Bently Nevada Corporation
1631 Bently Parkway South
Minden, NV 89423
Telephone: (775) 782-3611

SKF Condition Monitoring
4141 Ruffin Road
San Diego, CA 92123
Telephone: (858) 496-3400
Fax: (858) 496-3531

Computational Systems, Inc.
835 Innovation Drive
Knoxville, TN 37932
Telephone: (865) 675-2110
Fax: (865) 218-1401

6.5.6.2 Service Companies

Industrial Research Technology
Bethlehem, PA - Pittsburgh, PA -
Cleveland, OH - Detroit, MI - Chicago, IL -
Charleston, SC
Telephone: (610) 867-0101 or
1-800-360-3594
Fax: (610) 867-2341

Computational Systems, Inc.
835 Innovation Drive
Knoxville, TN 37932
Telephone: (865) 675-2110
Fax: (865) 218-1401

VibrAlign
530G Southlake Boulevard
Richmond, VA 23236
Voice: (804) 379-2250
Fax: (804) 379-0189
Toll Free: 800-394-3279
Email: info@vibralign.com

SKF Condition Monitoring
4141 Ruffin Road
San Diego, CA 92123
Telephone: (858) 496-3400
Fax: (858) 496-3531

6.5.6.3 Internet Resource Sites

Plant-maintenance.com
- Training material
- Industry links
- Free software
  - FFT/CMMS/Inventory control
- Technical articles
- Maintenance related articles

www.bksv.com/bksv/
- Products
- Industry articles
- Links

www.skfusa.com
- References and links
- Articles
- Products
- Training.

6.6 Motor Analysis

6.6.1 Introduction

When it comes to motor condition analysis, infrared (IR) and vibration will not provide all the answers required to properly characterize motor condition. Over the past several years, motor condition analysis techniques have evolved from simple meggering and hi-pot testing into testing techniques that more accurately define a motor's condition. Motor faults or conditions like winding short-circuits, open coils, improper torque settings, as well as many mechanically related problems can be diagnosed using motor analysis techniques. Use of these predictive maintenance techniques and technologies to evaluate winding insulation and motor condition has not grown as rapidly as other predictive techniques. Motor analysis equipment remains fairly expensive and proper analysis requires a high degree of skill and knowledge. Recent advances in equipment portability and an increase in the number of vendors providing contracted testing services continue to advance predictive motor analysis techniques. Currently, more than 20 different types of motor tests exist, depending on how the individual tests are defined and grouped. The section below provides an overview of two commonly used tests.

6.6.2 Motor Analysis Test

6.6.2.1 Electrical Surge Comparison

In addition to ground wall insulation resistance, one of the primary concerns related to motor condition is winding insulation. Surge comparison testing can be used to identify turn-to-turn and phase-to-phase insulation deterioration, as well as a reversal or open circuit in the connection of one or more coils or coil groups. Recent advances in the portability of test devices now allow this test technique to be used in troubleshooting and predictive maintenance. Because of differences in insulation thickness, motor winding insulation tends to be more susceptible to failure from the inherent stresses existing within the motor environment than ground wall insulation. Surge comparison testing identifies insulation deterioration by applying a high frequency transient surge to equal parts of a winding and comparing the resulting voltage waveforms. Differences seen in the resulting waveforms are indicative insulation or coil deterioration. A properly trained test technician can use these differences to properly diagnose the type and severity of the fault. In addition to utilization of this motor analysis technique in a predictive maintenance program, it can also be used to identify improper motor repair practices or improper operating conditions (speeds, temperature, load).

Surge comparison testing is a moderately complex and expensive predictive maintenance technique. As with most predictive maintenance techniques, the greatest saving opportunities do not come directly from preventing a catastrophic failure of a component (i.e., motor) but rather the less tangible cost saving benefits. Reduced downtimes, ability to schedule maintenance, increased production, decreased overtime, and decreased inventory cost are just a few of the advantages of being able to predict an upcoming motor failure.

6.6.2.2 Motor Current Signature Analysis

Another useful tool in the motor predictive maintenance arsenal is motor current signature analysis (MCSA). MCSA provides a non-intrusive method for detecting mechanical and electrical problems in motor-driven rotating equipment. The technology is based on the principle that a conventional electric motor driving a mechanical load acts as a transducer. The motor (acting as a transducer) senses mechanical load variations and converts them into electric current variations that are transmitted along the motor power cables. These current signatures are reflective of a machine's condition and closely resemble signatures produced using vibration monitoring. These current signals are recorded and processed by software to produce a visual representation of the existing frequencies against current amplitude. Analysis of these variations can provide an indication of machine condition, which may be trended over time to provide an early warning of machine deterioration or process alteration.

Motor current signature analysis is one of the moderately complex and expensive predictive techniques. The complexity stems in large part from the relatively subjective nature of interpreting the spectra, and the limited number of industry-wide historical or comparative spectra available for specific applications.

6.6.3 System Applications

- Stem packing degradation
- Incorrect torque switch settings
- Degraded stem or gear case lubrication
- Worn gear tooth wear
- Restricted valve stem travel
- Obstructions in the valve seat area
- Disengagement of the motor pinion gear
- Improper seal/packing installation
- Improper bearing or gear installation
- Inaccurate shaft alignment or rotor balancing
- Insulation deterioration
- Turn-to-turn shorting
- Phase-to-phase shorting
- Short circuits
- Reversed or open coils.

6.6.4 Equipment Cost/Payback

As indicated earlier, motor analysis equipment is still costly and generally requires a high degree of training and experience to properly diagnosis equipment problems. A facility with a large number of motors critical to process throughput may find that ownership of this technology and adequately trained personnel more than pays for itself in reduced downtime, overtime cost, and motor inventory needs. Smaller facilities may find utilization of one of the many contracted service providers valuable in defining and maintaining the health of the motors within their facility. As with most predictive maintenance contract services, cost will range from $600 to $1,200 per day for on-site support. Finding a single motor problem whose failure would result in facility downtime can quickly offset the cost of these services.

6.6.5 References/Resources

The references and resources provided below are by no means all-inclusive. The listed organizations are not endorsed by the authors of this guide and are provided for your information only. To locate additional resources, the authors of this guide recommend contacting relevant trade groups, databases, and the world-wide web.

6.6.5.1 Equipment Resources

Computational Systems, Inc.
835 Innovation Drive
Knoxville, TN 37932
Telephone: (865) 675-2110
Fax: (865) 218-1401

Chauvin Arnoux®, Inc.
d.b.a. AEMC® Instruments
200 Foxborough Boulevard
Foxborough, MA 02035
Telephone: (508) 698-2115 or (800) 343-1391
Fax: (508) 698-2118
Email: sales@aemc.com

AVO International
4651 S. Westmoreland Road
Dallas, TX 75237-1017
Telephone: (800) 723-2861
Fax: (214) 333-3533

Baker Instrument Company
4812 McMurry Avenue
Fort Collins, CO 80525
Telephone: (970) 282-1200 or (800) 752-8272
Fax: (970) 282-1010

6.6.5.2 Service Companies

Industrial Technology Research
Bethlehem, PA - Pittsburgh, PA -
Cleveland, OH - Detroit, MI - Chicago, IL -
Charleston, SC - Hamilton, ONT
Telephone: (610) 867-0101 or (800) 360-3594
Fax: (610) 867-2341

Littlejohn-Reuland Corp.
4575 Pacific Boulevard
Vernon, CA 90058
Telephone: (323) 587-5255
Fax: (323) 581-8385

Tru-Tec Services, Inc.
Magna-Tec
Telephone: (800) 232-8411

UE Amarillo
5601 W. Interstate 40
Amarillo, TX 79106-4605
Telephone: (806) 359-2400
Fax: (806) 359-2499

SHERMCO Industries, Inc.
Dallas
2425 East Pioneer Drive
Irving, TX 75061
Telephone: (972) 793-5523 or 1-888-SHERMCO
(Toll Free)
Fax: (972) 793-5542

6.6.5.3 Internet Site Resources

www.ic.ornl.gov
- On-line analysis system information
- Technology information contact resources

www.mt-online.com
- Technology overview
- Technology vendors
- Industry articles

www.reliabilityweb.com
- Service companies
- Training services
- Software links (including Motor Master)

6.7 Performance Trending

6.7.1 Introduction

In addition to the general preventive maintenance we perform, or have performed on our vehicles, many of us log and trend important parametric information related to the health of our vehicles and use this information to determine maintenance needs. We calculate and trend our cars mileage per gallon of gas. We track engine temperature and oil pressure. We track oil usage. This information is then used to define when vehicle maintenance is required. Maintenance activities such as tune-ups, thermostat replacement, cooling system flushes, belt replacements, oil seal replacements, etc., may all be originally stimulated by vehicle parametric information we trend.

Utilization of this performance trending approach can also be a valuable tool in maintaining the health and operational performance of the components in our facilities/plants. By logging and trending the differential pressure across a supply or discharge filter in the HVAC system, we can determine when filter replacement is required, rather than changing the filter out at some pre-defined interval (preventive maintenance). Logging and trending temperature data can monitor the performance of many heat exchangers. This information can be used to assist in the scheduling of tube cleaning. It may also serve as an indication that flow control valves are not working properly or chemical control measures are inadequate. Perhaps a decrease in heat exchanger performance, as seen by a change in delta-temperature, is due to biological fouling at our cooling loop pump suction. An increase in boiler stack temperature might be an indication of tube scaling. We may need to perform tube cleaning and adjust our chemistry control measures. Changes in combustion efficiency may be indicative of improperly operating oxygen trim control, fuel flow control, air box leakage, or tube scaling.

The key idea of performance trending is that much of the equipment installed in our facilities is already provided with instrumentation that can be used to assist in determination of the health/condition of the related component. Where the instruments are not present, installation of a pressure-sensing or temperature-sensing device is generally easily performed and inexpensive. Many times this information is already being logged at some pre-defined interval but not being utilized.

6.7.2 How to Establish a Performance Trending Program

One of the first steps of any predictive maintenance program is to know what equipment exists in your facility. First, generate a master equipment list, then prioritize the equipment on the list to define which pieces of equipment are critical to your facility's operation, important to personnel safety, or can have a significant budget impact (either through failure or inefficient operation).

Evaluate what parametric data should/could be easily collected from installed or portable instrumentation to provide information related to the condition/performance of the equipment on the master list based on your equipment prioritization.

Determine what, if any, of the defined data is already collected. Evaluate if any related parametric information is currently being tracked and if that information provides information regarding a components/systems condition or efficiency. Terminate the collection of information not useful in the evaluation of a component's condition/efficiency unless required by other administrative requirements.

Define and install instrumentation not currently available to monitor a critical component's condition/efficiency.

Log the information at some frequency defined by plant engineering or operational staff. For example, the frequency may be every 4 hours while operating or may simply be a single reading after reaching steady-state conditions, depending on the data evaluation needs.

Provide collected data to individual with knowledge and background necessary to properly trend and evaluate it.

6.7.3 System Applications

Generally, any plant component with installed, or easily installed, instrumentation useful in evaluating the components condition, operation, or efficiency can be trended. Information can also be obtained using portable instrumentation, e.g., an infrared thermometer. Some general applications might be:

- Heat exchangers
- Filters
- Pumps
- HVAC equipment
- Compressors
- Diesel/gasoline engines
- Boilers.

6.7.4 Equipment Cost/Payback

The cost to establish an effective trending program is minimal and can provide one of the largest returns on dollars expended. Most plants have much of the instrumentation needed to gain the parametric information already installed. Today's instrumentation offers many cost-effective opportunities to gather information without having to incur the expense of running conduit with power and signal cabling. The information gatherers are generally already on the payroll and in many cases, already gathering the needed information to be trended. For the most part, establishing a trending program would require little more than using the information already gathered and currently collecting dust. Payback for the little extra money spent is quickly recovered in increased machine efficiency and decreased energy cost.

6.7.5 References/Resources

The resources provided below are by no means all-inclusive. To locate additional resources, the authors of this guide recommend contacting relevant trade groups, databases, and the world-wide web.

Although few Web sites provide specific information related to the performance trending methodology, several vendors do provide software to assist in data collection and analysis. A few of these vendors can be found at:

- http://www.monarchinstrument.com/ontime.htm.
- http://www.rtx.com/TrendLink.htm.